REMOTE SENSING APPLICATIONS IN FORESTRY

A report of research performed under the auspices of the

Forestry Remote Sensing Laboratory
School of Forestry and Conservation
University of California
Berkeley, California

A Coordinated Task Carried out in Cooperation with
the Pacific Southwest Forest and Range Experiment

for

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

REMOTE SENSING APPLICATIONS IN FORESTRY

REMOTE SENSING OF CHANGES IN MORPHOLOGY AND
PHYSIOLOGY OF TREES UNDER STRESS

by

Charles E. Olson, Jr.

School of Natural Resources
University of Michigan

Final Report   30 September 1972

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I

PREFACE

On October 1, 1965, a cooperative agreement was signed between
the National Aeronautics and Space Administration (NASA) and the U.S.
Department of Agriculture (USDA) authorizing research to be undertaken
in remote sensing as related to Agriculture, Forestry and Range Manage-
ment under funding provided by the Supporting Research and Technology
(SR&T) program of NASA, Contract No. R-09-038-002. USDA designated
the Forest Service to monitor and provide grants to forestry and range
management research workers. All such studies were administered by the
Pacific Southwest Forest and Range Experiment Station in Berkeley,
California in cooperation with the Forestry Remote Sensing Laboratory
of the University of California at Berkeley. Professor Robert N.
Colwell of the University of California at Berkeley was designated
coordinator of these research studies.

Forest and range research studies were funded either directly with
the Forest Service or by Memoranda of Agreement with cooperating univer-
sities. The following is a list of research organizations participat-
ing in the SR&T program from October 1, 1965, until December 31, 1972.

1. Forest Service, USDA, Pacific Southwest Forest and Range
Experiment Station, Berkeley, California.

2. Forest Service, USDA, Rocky Mountain Forest and Range Exper-
iment Station, Fort Collins, Colorado.

3. School of Forestry and Conservation, University of California,
Berkeley, California.

4. School of Forestry, University of Minnesota, St. Paul, Minnesota.

5. School of Natural Resources, University of Michigan, Ann Arbor, Michigan.

6. Department of Range Management, Oregon State University, Corvallis, Oregon.

This report summarizes the significant findings of this research and identifies research results which have been applied or are ready for application. In addition, the work carried on for the reporting period October 1, 1971, until December 31, 1972, is described in detail.

A listing of all research reports produced under NASA SR&T funding for forest and range studies can be found in the Appendix of this report.

ABSTRACT

This is the sixth annual progress report describing results of
continuing studies of forest trees subjected to various types of
stress. This is also the final report describing work performed for
the NASA Earth Resources Survey Program.

Three studies were active during the year, and all were designed
to complete work on previsual detection of Fomes annosus in pine
plantations.

Detailed analyses of photographic imagery obtained over the Ann
Arbor Test Site (NASA Site 190) during 1969 and 1970 revealed that the
Ektachrome Infrared (Type 8443) film was superior to Ektachrome Aero-
graphic (Type 2448), Infrared Aerographic (Type 2424), or Plus-X Aero-
graphic (Type 2402) films for detecting Fomes annosus damage. Four
scales were tested -- 1:6,000, 1:12,000, 1:24,000, and 1:40,000 -- and
the 1:6,000 coverage gave significantly better results than the smaller
scales. Of the four dates considered -- June-July, August, October,
and November -- the photography from the June-July period near the
beginning of the growing season gave more consistent and accurate
detection of Fomes annosus damage than did any of the others. Of far
more significance in controlling the accuracy of damage detection,
however, was the experience of the photo interpreter. The more expe-
rienced interpreters were consistently more accurate on all film types,
at all scales, and on all dates. Only the three best interpreters of
the ten participating in the study, performed well enough with any

combination of film, scale, and date to justify recommending a photo system for _Fomes annosus_ detection.

Ratio-processing of multispectral scanner data was investigated with data collected in June of 1970 and in June of 1972. Ratioing of the 1.5-1.8 and 1.0-1.4 μm channels gave good results at detecting openings in the crown canopy and adjacent infected trees. Combined level slicing of the 1.5-1.8 μm channel and the 1.5-1.8 to 1.0-1.4 μm ratio permitted separation and recognition of forest litter in the openings and stressed trees adjacent to the openings. Indication of stress at locations without canopy openings may prove to be true cases of previsual detection of _Fomes annosus_.

A planned semi-operational test of a previsual detection technique based on the June, 1972 overflight was planned. This test could not be completed because the flight data and imagery were not received until 5 November 1972.

ACKNOWLEDGEMENTS

Several references to events that occurred after the time period

covered by this report will be found in the text. This report was submitted late. The delay was occasioned by our desire to reach a definitive conclusion regarding previsual detection of <u>Fomes annosus</u>. Although Mission 57M was flown on 5 June 1972, the imagery was not received from NASA until 5 November 1972. All funding for this effort ceased on 30 April 1972, and all work other than report writing was terminated on 31 October 1972. Thus, our delay of this report did not lead to the result intended. My thanks to the contract monitors at the Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, for their patience during this delay.

TABLE OF CONTENTS

REMOTE SENSING OF CHANGES IN MORPHOLOGY
AND PHYSIOLOGY OF TREES UNDER STRESS

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INTRODUCTION

Modern remote sensors offer considerable promise for early
detection of plant stress when the energy relationships associated
with such stress are understood. Controlled studies of reflectance
and emittance characteristics of foliage on trees subjected to varying
kinds and severity of stress contribute to such understandings. A
list of reports describing work done at The University of Michigan and
supported wholly, or in part, under National Aeronautics and Space
Administration (NASA) Contract No. R-09-038-002 is incorporated in the
overall list of reports from the NASA-USDA nationwide project and
appears elsewhere in the report. Our present report, summarizing work
completed under this same contract during the period from 1 October
1971 through 30 September 1972, is the Final Report on this project.
Previous reports have described several discrete but related studies
which were conducted as part of this project. Of these, only that
dealing with aerial detection of _Fomes annosus_ (Fr.) Cooke was active
during this reporting period. _Fomes annosus_ is a root- and heart-
rotting fungus that attacks conifers worldwide. The disease is a

major cause of cull, mortality, and growth loss in Europe (Grieg and Burdekin, 1970), and it is becoming an increasingly serious problem in the Southeastern United States (Southern Forest Pest Notes, 1972).

The Test Site

All field work was conducted in the Ann Arbor Test Site (NASA Site 190), approximately 50 nautical miles west of Detroit, Michigan. The site is located in an area of morainal topography at an elevation of approximately 330 meters above sea level. Upland and bottomland stands of both conifers and broadleaved trees are present, but this study is concerned with two areas of planted pines. Eastern white pine (Pinus strobus L.) and red pine (P. resinosa Ait.) are the most common species, but Scots pine (P. sylvestris L.), at least two species of spruce (Picea spp.), one hemlock (Tsuga sp.) and tamarack (Larix laricina (DuRoi) Cook) are present in the vicinity of the test site.

Fomes annosus infections were discovered near Bessey Lake in the Sharonville State Game Area in 1968 and at the University of Michigan's Stinchfield Woods property in 1969. These two locations within the total Ann Arbor Test Site have been monitored since the infection centers were first discovered.

Results Previously Reported

Airborne data were obtained over the test site in early August and late November 1969 (Mission 6M, 7M, and 8M) and on five dates during 1970 (Missions 15M, 20M, 24M, and 26M). All missions were flown

2

by the University of Michigan C-47 aircraft and provided both multi-spectral scanner (MSS) data and photography from four 70mm cameras. Black-and-white panchromatic and infrared film were in two of the cameras and color and color infrared film in the other two. Equipment malfunctions made some of the data unusable.

In 1970, we reported that recently attacked trees were easily detected on color infrared photography at scales of 1:48,000 and larger. Detection was also accomplished with normal color, and both panchromatic and infrared black-and-white films at scales of 1:24,000 and larger. The attacked trees appeared lighter toned on panchromatic and darker toned on infrared films than healthy teees. After attacked trees have died, dark-toned openings in the crown canopy develop (largely the result of shadowing) and mask the dead stems. Analysis of the MSS imagery from 1969 indicated that infection centers could be detected in any reflective band, but that attacked trees were detectable on thermal imagery obtained in August but not on that obtained in November (Olson, et al, 1970).

Work completed during this reporting period was conducted as three separate but related studies. These are described below.

STUDY I. PHOTOGRAPHIC DETECTION OF Fomes annosus IN PINE PLANTATIONS
(Study Leader: Glenn R. Miller)

The primary aim of this study was to determine quantitatively the accuracy with which experienced photo interpreters could detect the presence of Fomes annosus in one plantation at the Sharonville State Game Area location. The 70mm photography from the six missions flown

in 1969 and 1970 provided 64 possible combinations of scale, film, and data. Of these, only 43 combinations were suitable for interpretation, and only four sets of black-and-white panchromatic film were available. Since the small number of interpretable gray levels in the panchromatic film prevents recording of consistently interpretable tonal separations for distinguishing diseased from healthy trees, the panchromatic film was not included in the study. The one disease characteristic consistently detectable on the panchromatic photography at the scales available was canopy opening. A canopy opening is not considered sufficient evidence to conclude that diseased trees or infection centers are present.

Elimination of the black-and-white panchromatic film left three film/filter combinations in the study: Infrared Aerographic (Type 2424) with a Wratten 89B filter, Ektachrome Aerographic (Type 2448) with a Wratten 1A filter, and Infrared Ektachrome Aerographic (Type 8443) with a Wratten 15 filter. Photography used in the test was from flights in June-July, August, and October of 1970 and from November of 1969. Four scales were available for each date: approximately 1:6,000, 1:12,000, 1:24,000 and 1:40,000. Ten interpreters participated in the test.

Methods

Third-generation transparencies were used for the interpretation study. These were cut from 70mm rolls and mounted for stereoscopic viewing on clear plastic sheets. A plastic overlay was placed over one frame of each of the stereo pairs, to indicate the location of 10

one-quarter acre circular plots drawn to correct scale. Each set of stereo transparencies was interpreted over a light table with the interpreter's choice of viewing aids. Bausch and Lomb Zoom-90 stereo-scopes were available, but all interpreters elected to use 2X pocket stereoscopes for the basic interpretation. Each interpreter was given a written introduction and instruction list along with two keys for identifying the local tree species at Sharonville. Examples in stereo of diseased trees on each of the four film-filter types were included to familiarize the interpreters with the typical aerial appearance of the crowns of diseased red pine and white pine.

Interpreters were told that some of the plots had disease and some did not, with no indication of the actual number in each class. They were also told that it was arbitrarily twice as serious to call a diseased plot undiseased as it was to call an undiseased plot diseased. Despite this the interpreters stated that in most instances of uncertainty, when there was no photographic evidence available to warrant calling a plot diseased, they considered the plot undiseased. For each plot the interpreter decided as conscientiously as possible if he could detect diseased trees within the plot boundary. The interpreters were asked to work from small scale to large scale to reduce the bias possible when working from a large scale to a smaller scale.

Six of the ten plots contained diseased trees, with evidence of disease ranging from yellow-green crowns to dead trees with few remaining branches. The interpretation of each plot was scored as 0 if correctly interpreted, 1 if called diseased when undiseased, and 2 if

called undiseased when diseased. Scores were then added for all 10

plots on each stereo pair; all correct totaled 0, and all incorrect

totaled 16.

Results of the test were tabulated and analyzed with the BMDX64

general linear hypothesis model for analysis of variance of the Univer-

sity of Michigan Statistical Research Laboratory. This model is capa-

ble of handling analysis of variance problems with missing data sets.

The amount of missing photography made this necessary.

Results

The scores of each interpreter, on each scale and film type, and

on each of the four sampling dates are shown on Table 1. A score of

16 means that all plots were misclassified, a score of 12 resulted if

all 10 plots were classed as healthy, and a purely random classification

should result in an average score of 8. The large number of scores

over 10 indicates that photo detection of _Fomes annosus_ infection cen-

ters is not a simple inventory task. Interpreters 2, 3, and 4 (partic-

ularly interpreter 4) appear to have consistently lower scores than the

others. These observations are supported by the analysis of variance

results (Table 2).

Since the scoring process gave low scores for accurate interpreta-

tions, the regression coefficients with the largest negative values

indicate the most important variables. Based on this test, a photo

mission for _Fomes annosus_ detection should be flown in the spring or

early summer (June-July), with Ektachrome Infrared film, and at a scale

of 1:6,000 or larger. More important than all of these specifications,

TABLE 1. Summary of interpreter scores for detecting _Fomes annosus_ damage from aerial photographs taken with different films, at different scales on different dates. (High numbers mean poor results).

Date and Interpreter	SCALE AND FILM TYPE											
	1:6,000			1:12,000			1:24,000			1:40,000		
	2424	2448	8443	2424	2448	8443	2424	2448	8443	2424	2448	8443
June–July												
1	*	11	1	*	6	6	8	6	9	10	8	7
2		4	5		4	6	9	9	6	10	9	8
3		5	2		7	4	5	2	7	7	10	6
4		4	1		3	3	3	3	8	8	2	0
5		6	7		12	12	13	12	13	12	12	12
6		8	7		5	8	6	8	13	10	12	7
7		10	8		5	7	6	11	11	10	10	7
8		8	11		5	4	12	4	4	13	12	6
9		4	7		8	5	14	4	10	12	12	12
10		9	7		10	10	12	10	10	11	10	9
August												
1	*	7	14	5	6	12	8	11	7	7	4	7
2		5	3	4	8	5	6	5	6	12	12	3
3		4	6	6	6	7	7	7	5	6	7	4
4		3	1	5	4	3	2	5	2	9	2	4
5		9	5	12	12	14	12	12	12	12	12	12
6		8	6	13	8	8	12	12	8	12	12	6
7		10	10	12	10	10	12	10	10	12	10	13
8		8	2	12	12	6	12	12	12	12	12	12
9		12	10	13	6	9	12	9	8	12	11	3
10		10	4	12	2	11	12	9	3	10	10	7
October												
1	*	6	10	13	10	6	*	6	8	13	12	8
2		2	7	7	4	0		6	6	12	12	6
3		7	7	8	7	7		6		3	6	15
4		5	2	10	3	4		4	5	10	8	3
5		8	8	12	12	10		12	12	12	12	12
6		8	6	12	8	11		12	11	12	12	12
7		6	7	13	12	12		12	13	11	12	11
8		6	5	12	8	12		6	8	12	12	10
9		9	3	8	7	3		8	4	9	12	4
10		7	7	14	8	6		14	12	11	10	11
November												
1	*	4	*	4	6	4	6	3	5	9	*	*
2		8		10	10	10	7	11	5	12		
3		9		7	9	9	7	9	9	10		
4		4		4	3	5	3	3	3	5		
5		12		12	12	12	12	12	12	12		
6		8		12	6	10	12	10	12	12		
7		10		12	12	10	12	8	12	12		
8		4		12	5	12	12	1	12	12		
9		10		12	10	4	10	8	8	12		
10		10		12	11	11	12	8	8	12		

* Usable imagery with this film, at this scale, on this date not available.

Table 2. Regression coefficients calculated from the BMDX64 Statistical Model.

Source of Variation	Regression Coefficient
Date	
June-July	-0.5446
August	-0.1016
October	0.3353
November	0.3109
Scale	
1:6,000	-1.2017
1:12,000	-0.9644
1:24,000	0.2017
1:40,000	1.0964
Film Type	
Color Infrared (8443)	-0.8119
Normal Color (2448)	-0.2583
Infrared Aerographic (2424)	1.0702
Interpreter	
1	-0.2368
2	-1.3590
3	-1.6410
4	-4.2821
5	2.9487
6	1.2564
7	1.9231
8	0.6667
9	0.2051
10	0.5128

The analysis of variance without interactions indicated that the differences between scale, film type, and interpreters are significant at the 5 percent level, and the difference between dates is significant at the 10 percent level.

however, would be obtaining the services of Interpreter 4.

The differences in interpreter performance are worthy of further discussion. Of the ten interpreters, all but 2, 5, 6, and 10 had completed the basic air-photo interpretation course at the University of Michigan, while interpreters 2 and 10 had completed air-photo interpretation courses elsewhere and had served as Teaching Fellows in the course at the University of Michigan. Interpreter 4 had recently completed a land-use mapping project covering nearly 1200 square miles, and interpreter 3 had just completed a similar project covering approximately 36 square miles. The increased experience provided by these two projects is the only known explanation for the greater accuracy of these two interpreters. Interpreter 5 had been trained in military photo interpretation schools but had not had any significant experience in vegetation interpretation.

STUDY II. RATIO PROCESSING OF MULTISPECTRAL DATA FOR PREVISUAL DETECTION OF Fomes annosus INFECTION CENTERS

This phase was directed by N. Roller and F. Thomson at the University of Michigan Willow Run Laboratories as part of NASA Contract NAS9-9784. Much of the material included here has been extracted from Roller and Thomson's (1972) report to NASA.

The ratio work was based on analyses of the laboratory measurements of W. G. Rohde (1971) and detailed interpretation of video imagery from the 1970 flight program. Both digital and analog computer ratio processing was performed on selected spectral channels of multispectral data collected in June, 1970 and June, 1972 (Phase III) on

flights of the University of Michigan C-47 aircraft. Considerable

analysis, cross-correlation with photography, and field checking were

necessary supplements to the actual data processing. Initial expec-

tations that ratio processing alone would be sufficient to delineate

stress caused by Fomes annosus infections proved erroneous. Careful

examination of ratio results revealed that canopy openings were con-

fused with stressed trees. Joint slicing of the ratio and 1.5-1.8 μm

video data were required to separate the two classes.

.Study Plan

Previous work indicated that ratio-processing of multispectral

scanner (MSS) data would enhance Fomes annosus detection. Rohde's

work (1971) pointed to ratios of the 1.5-1.8 and 1.0-1.4, and the

1.5-1.8 and 2.0-2.6 μm bands. Detailed analysis of the available

imagery evoked interest in the ratio of the 0.8-1.0 and 8.0-13.5 μm

bands. Miller's work (Study I of this report) indicated that results

were better early in the growing season than later.

Two locations were selected for study. The Sharonville site

would be used for developing the ratioing procedure(s) and the

Stinchfield Woods site would be used as a semi-operational test of

the ratioing technique(s). Stinchfield Woods is approximately 20

miles northeast of the Sharonville site and would provide an indication

of the general utility of the technique(s) developed.

MSS data from Mission 15M of 8 June 1970, and the expected MSS

data from the overflight scheduled for 5 June 1972 (Mission 57M)

were chosen for processing. The 1970 data had been collected with

the 2-ended scanner, and registration problems between the two ends

made ratioing the 0.8-1.0 and 8.0-13.5 μm channels impractical. Three

channels of near infrared data from the 1,500 ft. run were selected

for processing: 1.0-1.4, 1.5-1.8, and 2.0-2.6 μm. The 2.0-2.6 μm

data were exceptionally noisy. During the Stinchfield Woods run,

the detector had frosted, and signal strength was only about one-half

normal. The same three near infrared channels, and the 9.3 to 11.7 μm

channel from the new single-end scanner, were selected from the 1972

data. All data were of high quality and individual tree crowns were

resolved.

Methods

Both SPARC (analog) and digital processing methods were employed.
The two methods will be described separately.

SPARC Processing

Video prints of all three channels and two ratio maps -- $\frac{1.5 - 1.8}{1.0 - 1.4}$

and $\frac{1.5 - 1.8}{2.0 - 2.6}$ -- were made from the 1970 data for each test site. Lamp

calibration data were used to normalize the signals before ratio pro-
cessing. Both video prints and ratio maps were adjusted to present as

correct an aspect ratio as possible.

Video prints of the four channels selected from the 1972 data, and

three ratios -- $\frac{1.5 - 1.8}{1.0 - 1.4}$, $\frac{1.5 - 1.8}{2.0 - 2.6}$, and $\frac{1.0 - 1.4}{9.3 - 11.7}$ -- were made for

each test site. Lamp calibration data and an internal thermal reference
were used to normalize the signals before ratio processing. As with

the 1970 data, video prints and ratio maps were adjusted to present

as correct an aspect ratio as possible and gray scales were printed

$$\frac{1.5 - 1.8 \ \mu m}{1.0 - 1.4 \ \mu m}$$

$$\frac{1.5 - 1.8 \ \mu m}{2.0 - 2.6 \ \mu m}$$

Figure 1. SPARC-generated ratio maps of the Sharonville Test Site for 5 June 1970 data set. White arrows indicate Fomes annosus infection centers (light-toned).

$$\frac{1.5 - 1.8 \ \mu m}{1.0 - 1.4 \ \mu m}$$ $$\frac{1.5 - 1.8 \ \mu m}{2.0 - 2.6 \ \mu m}$$ $$\frac{1.0 - 1.4 \ \mu m}{9.3 - 11.7 \ \mu m}$$

Figure 2. SPARC-generated ratio maps of the Sharonville Test Site for the 5 June 1972 data set. White arrows indicate Fomes annosus infection centers (light-toned).

to provide a calibration index for the video and ratio map densities.

Digital Processing

Digital processing involved several steps, as shown in the flow-diagram in Figure 3. Flow proceeded from top to bottom as described below.

Preliminaries. Processing in this mode began with the duplication of the original analog tapes. The data were then digitized, using the A/D conversion equipment. The data were packed, edited and put into ADTEST format, using the ADTEST2 program. This provides 420 digital points per scan line, corresponding to 2.5 milliradian resolution, and every scan line was digitized.

It was not possible to complete a successful A/D conversion for the 1972 data before the project was terminated. Signal breakup in all channels, thought to be the consequence of an A/D converter mal-function, twice resulted in output data unsuitable for further processing. For this reason, digital processing was confined to the 1970 data.

Preprocessing. AUTOCAL was used to determine the lamp and sun sensor signal locations and their magnitudes for calibration purposes. The CSD program was initially run clamping the data to the dark level and scaling the signal to the sun sensor. The effect of excessive noise in the 2.0 - 2.6 channel made it necessary to work with clamped data only, thus avoiding the violent, erroneous shifts in signal levels resulting from noise in the lamp signal. After a clamped-only version of CSD had been run, an effort was made to remove the angular
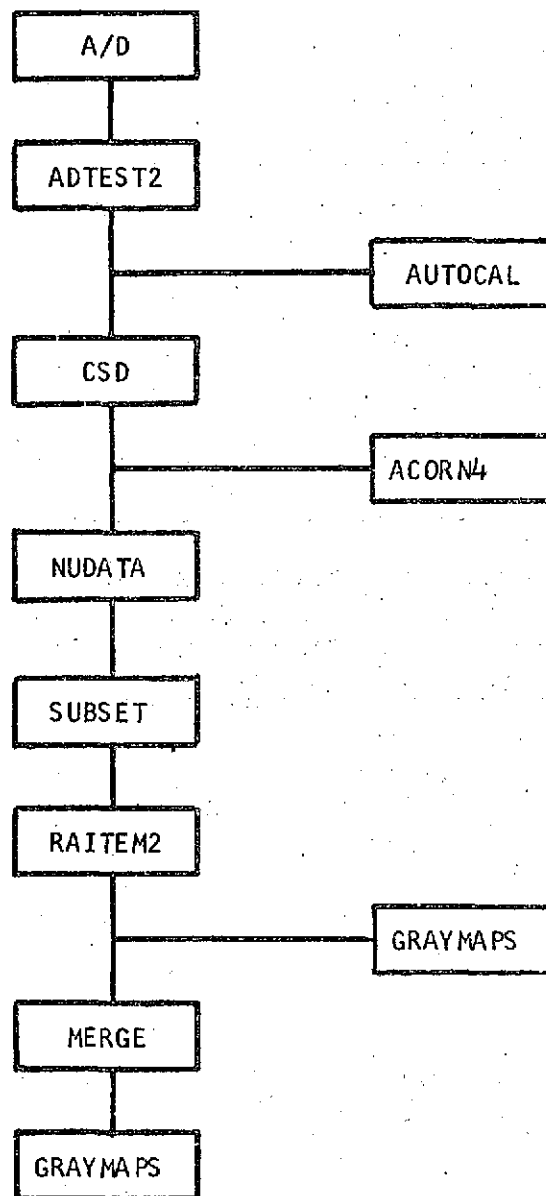
14

Figure 3. Flow chart of digital processing for 6/8/70 data.

variation in radiance across the scene using the ACORN4 program.
Because of the vastly different scene radiance for brush and conifers
at the Stinchfield Woods site, where each cover type was concentrated
at an opposite end of the scan line, a "conifer-only" correction coef-
ficient was used. NUDATA was run using the correction coefficients
derived from ACORN4 and yielded data ready for ratio-processing.

Processing. A special tape containing only the data to be ratioed
was created through the use of the SUBSET program. RAITEM2 was then
used to produce output data that represented the ratioed signals of
two input channels. These ratioed data were printed out in the form
of GRAYMAPs. After an examination of these maps, it was decided to
combine one of the ratios with an original data channel in hopes of
obtaining a more powerful means of discriminating between targets of
interest. Using the editing feature of GRAY2, a final GRAYMAP of an
original data channel, 1.5 - 1.8 µm, was produced, with color-coded
symbols marking infection sites mapped on the basis of threshold
values in the $\frac{1.5 - 1.8 \text{ µm}}{1.0 - 1.4 \text{ µm}}$ ratio, the control channel.

Merged data. The data for the 1.5 - 1.8 µm channel were merged
with the ratio of the same data to the 1.0 - 1.4 µm channel. Level
slicing of the merged data gave a two-dimensional discriminant matrix
for separating healthy conifers, broadleaved trees, forest litter,
and diseased conifers (Table 3).

Table 3. Discriminant matrix for diseased conifers based on level slicing of merged MSS data.

Signal Level *		1.5 - 1.8 μm Channel		
		0 0.3711	0.4883	10.000
Ratio $\dfrac{1.5-1.8\ \mu m}{1.0-1.4\ \mu m}$	0	Healthy Conifers	Healthy Conifers	Broadleaved Trees & Brush
	0.539	Forest Litter	Diseased Conifers	Broadleaved Trees & Brush
	2.000			

* Signal levels in mW cm^{-2} $ster^{-1}$ μm^{-1}.

Digital processing of the 1972 data was not completed because of monetary constraints on both the processing and basic contracts.

Discussion. Prior to this study the use of ratio-processing for the detection of stressed vegetation was an unknown quantity. For this reason, the analysis emphasis of this project has taken several different turns during the course of the data processing, reflecting a growing appreciation of the capabilities and limitations of this technique. Because of software constraints on ratio magnitude, one of the first areas investigated was the predicted magnitudes of the proposed radiance ratios. The availability of spectral curves for Fomes annosus-infected and healthy red pine foliage provided a starting place.

Calculation of the average reflectance for infected and healthy red pine needles in each of the near infrared spectral bands and multiplication of this figure by the available solar irradiance in each

of these bands provided an estimation of the energy reflected to the scanner from each type of foliage. These values were then used to form the ratios. Based on these calculations, the $\frac{1.5 - 1.8 \text{ }\mu m}{2.0 - 2.6 \text{ }\mu m}$ ratio gave indications of providing the best discrimination between healthy and infected foliage. In practice, this was not the case.

Several factors may, in part, account for this. First, an average value for solar irradiance had to be assumed because of the lack of ground truth measurements. Secondly, the extrapolation of needle spectra to approximate those of a forest stand is tenuous, at best. And finally, there is the problem of the composition of needle maturity seen by the scanner. To assess this last parameter, and to gain acquaintance with the test site, several field trips were conducted.

Three different trips were made to the Sharonville Test Site; one in each of the months, June, July, and August. Several things were accomplished as a result of these trips. The first involved obtaining estimates of the percentage of mature and immature needles present on the trees at different times of the growing season. From this work, it was determined that the scene in early June would be composed almost exclusively of mature foliage. Another significant contribution of the field work was the production of a rough topographic map of the site. This last effort was useful in evaluating the effects of micro-climate on the $\frac{1.0 - 1.4 \text{ }\mu m}{9.0 - 11.3 \text{ }\mu m}$ ratio.

Both SPARC and digital ratio maps prepared from the 1970 data contained conifer areas imaged in uniquely distinct tones that correlated with known pockets of _Fomes annosus_. Significantly, the $\frac{1.5 - 1.8 \text{ }\mu m}{1.0 - 1.4 \text{ }\mu m}$

ratio appeared the most effective and easy to interpret. Part of this may be attributable to the poor quality of the 2.0 - 2.6 data.

Comparison with aerial photography taken during the MSS data collection flight confirmed the identification of infection centers by the ratio maps, but also pointed up that little distinction was possible between holes in the canopy in which pine litter was visible, and known infected trees around the perimeter of the opening.

With the hope that a level slicing of the ratios would provide a separation of litter and infected trees, line prints were made of digital data, listing voltage levels for known areas of litter and diseased trees. The result was disappointing: the dynamic range of litter and infected trees overlapped.

By now, it was evident that the ratio itself was insufficient for selective identification of infection centers. A more powerful means of discrimination was necessary. Little was known about the spectral characteristics of pine litter, so a spectral curve was made on a Beckman spectrophotometer. It was found that litter is significantly less reflective than coniferous foliage in the 1.0 - 1.4 and 1.5 - 1.8 μm spectra bands.

Since the capability for delineating potential infection centers existed in the ratioed data, and the ability to separate litter from coniferous foliage existed in the 1.5 - 1.8 μm band (which also gives good forest species discrimination), it was decided to merge these data to obtain simultaneous discrimination of all targets of interest in one presentation. The result was a digital recognition map showing

diseased conifers in red. (Due to the cost of color reproduction, no copy is included in this report.)

The SPARC maps of the near infrared ratios for the 1972 data set yielded results similar to those obtained from the 1970 data except that the overall resolution was much improved. The $\frac{1.5 - 1.8 \text{ } \mu\text{m}}{1.0 - 1.4 \text{ } \mu\text{m}}$ ratio again delineated canopy openings extremely well. The $\frac{1.0 - 1.4 \text{ } \mu\text{m}}{9.0 - 11.3 \text{ } \mu\text{m}}$ ratio provided less positive results, but was useful in identifying hardwood forest and brush species mixed in the plantation, an aid in reducing false alarm identifications of infection centers.

Lack of a device permitting direct overlay of SPARC or digital recognition maps and aerial photography has made quantitative determinations of detection accuracy difficult. Through use of a VARISCAN film viewer, however, localized analysis of infection centers on the digital recognition map and projected film images appears to indicate considerable correlation. The appearance of a characteristic bull's-eye pattern of blue litter symbols surrounded by red diseased-conifer symbols (in digital results) in large infection centers provides additional encouragement, since it duplicates the natural pattern of a hole in the stand canopy with litter showing, surrounded by diseased trees.

Comparison of the 1970 digital recognition map with the 1972 SPARC results shows a correlation of indicated infected trees in 1970 with increased canopy opening in 1972. At present this is the only tangible proof of previsual detection, beyond ocular estimations. It was hoped that 70mm color photography flown concurrently with the 1972 June mission

20

could be used for direct comparison with the 1970 data, on an overlay basis, to assess previsual detection. This film is not yet available from NASA.

The original analysis scheme of this project was to develop an infection detection methodology, using the Sharonville Test Site data, and evaluate its effectiveness through processing of the Stinchfield Woods data. Because of the ease with which SPARC processing may be accomplished, it was possible to make ratio maps for Stinchfield Woods for both data sets. No merged data sets were made, though, nor any digital processing, beyond angle-correcting the data. This was in part prompted by a lack of ground truth for Stinchfield Woods, but more by a desire to concentrate upon completing the Sharonville data within the time and funding limits of the project.

For a number of reasons, this study cannot be considered complete. Yet it has defined and proved, to some degree, a methodology for locating and mapping <u>Fomes annosus</u> infection centers in forest stands.

Considering the estimated accuracy of this ratio-editing technique and its real time capability (less than one day turn-around time for SPARC processing), it should generate considerable interest among forest management groups.

STUDY III. A SEMI-OPERATIONAL TEST OF A <u>Fomes annosus</u> DETECTION SYSTEM

This study was based on the 5 June 1972 overflight of NASA Test Site 190 accomplished as part of Mission 57M. Ground truth data were collected at the Sharonville location, but project personnel deliberately avoided the Stinchfield Woods area. Procedures developed from

the Sharonville data were to be extrapolated to Stinchfield Woods, and we did not want to have the interpreters obtain ground truth information before identifying infection centers from the imagery.

This study could not be completed because imagery from this flight was not received from NASA until 5 November 1972, and the ratio-processing previously discussed (Study II) was not completed until approximately 31 October 1972. The ratio-processing was performed from tape-recorded data retained by the University of Michigan which did not have to be returned from NASA.

SIGNIFICANT ACCOMPLISHMENTS

In closing any final report it is appropriate to look back and identify the major milestones which have come and gone. This project began in 1965 and has seen many investigators during its seven year history. Although the specific studies conducted have varied, the central objective was always to gain a better understanding of the physiological and morphologic changes that occur in trees under stress and to gain a better understanding of the reflectance and emittance changes which accompany such stress.

Early work under this project identified the foliar reflectance and emittance changes of tree seedlings subjected to moisture stress. Greenhouse work with red pine (Pinus resinosa Ait.) and white pine (P. strobus L.) became the basis for extensive field tests of several remote sensors for detection and mapping of Black Hills beetle (Dendroctonus ponderosae Hopk.) attacks in South Dakota.

Concurrent work with yellow poplar (<u>Liriodendron tulipifera</u> L.)
revealed different patterns of reflectance change for leaves that
unfolded under stress than for leaves that attained full size before
being subjected to stress. Subsequent work revealed that these pat-
terns extend to other species and that two fundamental patterns exist
with one applying to ring-porous species that flush only once at the
beginning of the growing season, and the second applying to diffuse-
porous species that flush more or less continuously throughout the
growing season. Extension of these data revealed that pre-visual
detection of moisture stress (as a symptom of disease or insect attack)
is not a practical remote sensing capability in the 0.4 to 2.6 μm
spectral band with ring-porous species.

Specific work with the oak wilt disease caused by the fungus
<u>Ceratocystis fagacearum</u> (Bretz) Hunt showed that the disease pro-
duces visible symptoms so quickly after infection (about 15 days) that
aerial methods for pre-visual detection are not practicable.

Studies of the effects of high salinity on sugar maple (<u>Acer</u>
<u>saccharum</u> Marsh.) revealed that salt damage did not result from an
induced moisture stress resulting from high osmotic pressure of the
sap stream. The transition between dead and apparently healthy tissue
in leaves with visible browning at the tips was only one or two cells
wide and could not be detected photographically. Pre-visual detection
of salt damage was deemed impractical with camera systems, but statis-
tical analyses of the data led to the conclusion that ratio-processing
of multispectral scanner data in the 0.8 to 2.6 μm spectral region was

23

more promising.

Regression analyses of data on foliar moisture content and associated reflectance data resulted in equations for predicting oven-dry-weight moisture content of broadleaved foliage from a laboratory reflectance curve (r=0.93). When plants can be taken to the spectrophotometer, or the instrument to the plant, this equation provides a non-destructive method of estimating foliar moisture content of potential usefulness in many kinds of research studies.

Analyses of foliar reflectance data and differences in rooting habits between species led to a successful trial of the University of Michigan multispectral scanner and SPARC processor for automated species identification and type mapping. Separation of sugar maple, red oak (Quercus rubra Du Roi), white oak (Q. alba L.), black walnut (Juglans nigra L.), and black locust (Robinia pseudoacacia L.) from each other and from conifers was accomplished with sufficient accuracy to be useful as the first stage in a multistage inventory design in remote or inaccessible areas.

Laboratory data showed that leaves on seedlings under severe moisture stress have apparent temperatures 2° to 5° C. higher than leaves on well-watered trees. This difference is consistent for most of the daylight hours (9 am to 4 pm), indicating that the time window for thermal sensing is quite wide. Field trials showed that wind tends to reduce the potential difference between healthy and diseased trees and makes stress detection in a single thermal band difficult, or impossible. Ratioing techniques involving one or more thermal bands

appear more promising.

Ratio-processing of multispectral scanner data has also been shown to enhance detection of areas of _Fomes annosus_ damage in pine plantations. Some additional testing of this technique is required, but it appears that an operational technique using a two-channel line scanner is attainable.

In compiling this summary, I have been pleasantly surprised to recall how much has been accomplished. I also recall the amount of effort required to achieve these advances, and know how little has actually been learned when compared with what remains unknown. It is entirely possible that the most lasting and signifcant contributions of this project may prove to be the result of the training and education provided to the more than twenty research workers directly involved in the conduct of the several studies completed.

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APPENDIX A

NASA-USDA FORESTRY AND RANGE REMOTE SENSING RESEARCH PROGRAM
"REMOTE SENSING APPLICATIONS IN FORESTRY" SERIES

1966 Annual Reports

STAR* No.	Title
N67-19905	Carneggie, D. M., W. C. Draeger and D. T. Lauer. The use of high altitude, color and spectrozonal imagery for the inventory of wildland resources. Vol. I: The timber resource. School of Forestry and Conservation, University of California, Berkeley. 75 pages.
N66-39698	Carneggie, D. M., E. H. Roberts and R. N. Colwell. The use of high altitude, color and spectrozonal imagery for the inventory of wildland resources. Vol. II: The range resource. School of Forestry and Conservation, University of California, Berkeley. 22 pages.
N67-19939	Carneggie, D. M. and R. N. Colwell. The use of high altitude, color and spectrozonal imagery for the inventory of wildland resources. Vol. III: The soil, water, wildlife and recreation resource. School of Forestry and Conservation, University of California, Berkeley. 42 pages.
N66-39304	Heller, R. C. et al. The use of multispectral sensing techniques to detect ponderosa pine trees under stress from insect or pathogenic organisms. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 60 pages.
N66-39386	Lauer, D. T. The feasibility of identifying forest species and delineating major timber types in California by means of high altitude small scale aerial photography. School of Forestry and Conservation, University of California, Berkeley. 130 pages.
N66-39700	Wear, J. F. The development of spectro-signature indicators of root disease on large forest areas. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 24 pages.

*Available through NASA Scientific Technical and Information Facility, P. O. Box 33, College Park, Maryland 20740.

27

STAR No.	Title
N66-39303	Lent, J. D. Cloud cover interference with remote sensing of forested areas from earth-orbital and lower altitudes. School of Forestry and Conservation, University of California, Berkeley. 47 pages.
N66-39405	Weber, F. P. Multispectral imagery for species identification. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 37 pages.

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N68-17406	Draeger, W. C. The interpretability of high altitude multispectral imagery for the evaluation of wildland resources. School of Forestry and Conservation, University of California, Berkeley. 30 pages.
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N68-17671	Carneggie, D. M., C. E. Poulton and E. H. Roberts. The evaluation of rangeland resources by means of multispectral imagery. School of Forestry and Conservation, University of California, Berkeley. 76 pages.
N68-17378	Wear, J. F. The development of spectro-signature indicators of root disease on large forest areas. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 22 pages.
N68-17408	Heller, R. C., R. C. Aldrich, W. F. McCambridge and F. P. Weber. The use of multispectral sensing techniques to detect ponderosa pine trees under stress from insect or pathogenic organisms. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 65 pages.
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N69-25632   Carneggie, D. M. Analysis of remote sensing data for range resource management. School of Forestry and Conservation, University of California, Berkeley. 62 pages.

N69-16113   Lauer, D. T. Forest species identification and timber-type delineation on multispectral photography. School of Forestry and Conservation, University of California, Berkeley. 85 pages.

N72-74471   Driscoll, R. S. and J. N. Reppert. The identification and quantification of plant species, communities and other resource features in herbland and shrubland environments from large scale aerial photography. Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, USDA. 62 pages.

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N69-16390   Poulton, C. E., B. J. Schrumpf and E. Garcia-Moya. The feasibility of inventorying native vegetation and related resources from space photography. Department of Range Management, Agricultural Experiment Station, Oregon State University. 47 pages.

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N69-12159   Draeger, W. C. The interpretability of high altitude multispectral imagery for the evaluation of wildland resources. School of Forestry and Conservation, University of California, Berkeley. 68 pages.

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STAR No.	Title
N72-74472	Langley, P. G. and D. A. Sharpnack. The development of an earth resources information system using aerial photographs and digital computers. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 26 pages.
N69-15856	Olson, C. E. and J. M. Ward. Remote sensing of changes in morphology and physiology of trees under stress. School of Natural Resources, University of Michigan. 43 pages.

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N70-41162	Olson, C. E., J. M. Ward and W. G. Rohde. Remote sensing of changes in morphology and physiology of trees under stress. School of Natural Resources, University of Michigan. 43 pages.
N70-41164	Heller, R. C., R. C. Aldrich, W. F. McCambridge and F. P. Weber. The use of multispectral sensing techniques to detect ponderosa pine trees under stress from insect or diseases. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 59 pages.
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N70-41282	Colwell, R. N. et al. Analysis of remote sensing data for evaluating forest and range resources. School of Forestry and Conservation, University of California, Berkeley. 207 pages.
N70-41063	Poulton, C. E., E. Garcia-Moya, J. R. Johnson and B. J. Schrumpf. Inventory of native vegetation and related resources from space photography. Department of Range Management, Agricultural Experiment Station, Oregon State University. 66 pages.

STAR No.	Title
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**	Wilson, R. C. Potentially efficient forest and range applications of remote sensing using earth orbital spacecraft -- circa 1980. School of Forestry and Conservation, University of California, Berkeley. 199 pages.
**	Aldrich, R. C., W. J. Greentree, R. C. Heller and N. X. Norick. The use of space and high altitude aerial photography to classify forest land and to detect forest disturbances. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 36 pages.
**	Driscoll, R. S. and R. E. Francis. Multistage, multi-seasonal and multiband imagery to identify and quantify non-forest vegetation resources. Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, USDA. 65 pages.
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**	Meyer, M. P., D. W. French, R. P. Latham and C. A. Nelson. Vigor loss in conifers due to dwarf mistletoe. School of Forestry, University of Minnesota. 21 pages.
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N72-27375	Olson, C. E., W. G. Rohde and J. M. Ward. Remote sensing of changes in morphology and physiology of trees under stress. School of Natural Resources, University of Michigan. 26 pages.

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STAR No.	Title
N71-32815	Dana, R. W. Calibration of color aerial photography. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 14 pages.
N72-28327	Driscoll, R. S. and R. E. Francis. Multistage, multi-band and sequential imagery to identify and quantify non-forest vegetation resources. Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, USDA. 75 pages.
N72-28328	Amidon, E. L., D. A. Sharpnack and R. M. Russell. The development of an earth resources information system using aerial photographs and digital computers. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 7 pages.
N72-28324	Personnel of the Remote Sensing Research Work Unit. Monitoring forest land from high altitude and from space. Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service, USDA. 179 pages.
N72-28326	Poulton, C. E., D. P. Faulkner, J. R. Johnson, D. A. Mouat and B. J. Schrumpf. Inventory and analysis of natural vegetation and related resources from space and high altitude photography. Department of Range Management, Agricultural Experiment Station, Oregon State University. 59 pages.
N72-28325	Meyer, M. P., D. W. French, R. P. Latham, C. A. Nelson and R. W. Douglass. Remote sensing of vigor loss in conifers due to dwarf mistletoe. School of Forestry, University of Minnesota. 40 pages.
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33